Estimating Impervious Cover from Regionally Available Data

Sandra L. Bird and Linda R. Exum, U.S. Environmental Protection Agency, ORD/NERL Ecosystems Research Division, Athens, Georgia
Stephen Alberty and Christine Perkins, Computer Sciences Corporation, Athens, Georgia
Jim Harrison, U.S. Environmental Protection Agency, Water Management Division, Region IV, Atlanta, Georgia

U.S. Environmental Protection Agency

U.S. EPA Office of Research and Development
National Exposure Research Laboratory
Ecosystems Research Division

Introduction

Nonpoint source pollution (NPS) or pollution from diffuse sources such as urban/ suburban areas and farmlands is now recognized as the primary threat to water quality in the United States (USEPA, 1994). NPS pollution threats from urban and suburban development are increasing as the U.S. population rises. Along with this increase in development comes an increase in impervious surfaces–areas where infiltration of water into the underlying soil is prevented. Roadways and rooftops account for the majority of this impervious area.

Research in recent years has consistently shown a strong relationship between the percentage of impervious cover in a drainage basin and the health of the receiving stream. In a review of research on impervious cover, Schueler concluded that despite a range of different criteria for stream health, use of widely varying methods and a range of geographic conditions, stream degradation consistently occurred at relatively low levels of imperviousness (10 to 20%).

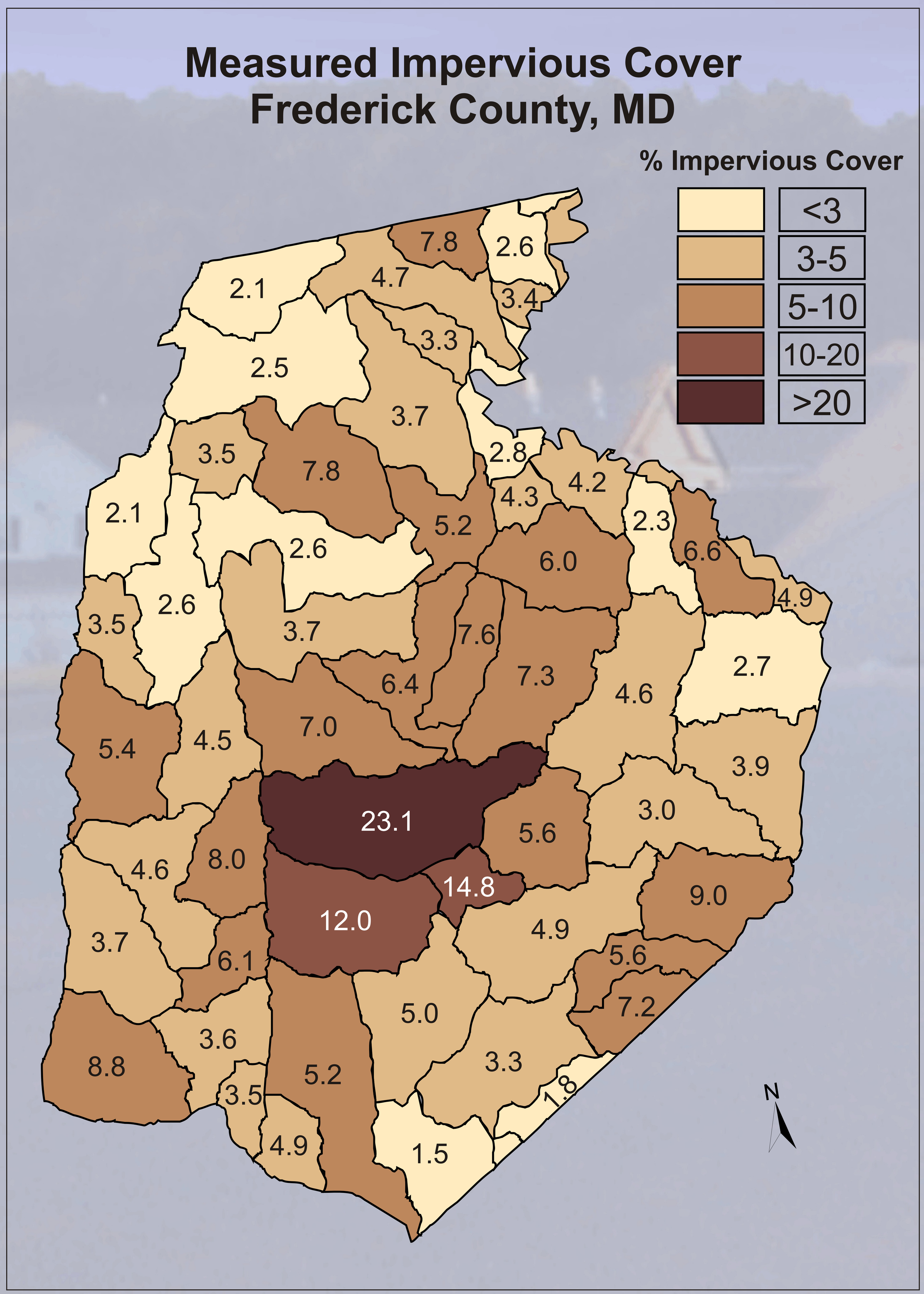
A number of approaches have been used for measuring and estimating impervious cover. While ground based surveys can be extremely accurate, these are typically prohibitively expensive. With the increased availability of high resolution satellite imagery, remote sensing techniques are becoming widely used to estimate impervious cover. Classified imagery such as that developed for the Multi Resolution Land Characteristics (MRLC) consortium (Loveland and Shaw, 1996; Vogelmann, 1998) identify urban areas based on impervious cover. A number of relationships between population density and impervious cover have been developed (Stankowski, 1972; Graham et al. 1974; Hicks and Woods, 2000) and city planners often use land-use zoning to do rapid estimates of total impervious area.

The objective of this study is to compare and evaluate the reliability of different approaches for estimating impervious cover including three empirical formulations for estimating impervious cover from population density data, estimation from categorized land cover data, and to explore the value of basing estimation techniques on a combination of data sources.

Test Data Set Development

An impervious cover test data set for 56 14-digit subwatersheds in Frederick County, MD was developed from digital orthophoto quarter quadrangles (DOQQ) from the U.S. Geological Survey (USGS). DOQQs are computer-generated versions of aerial photographs which have been orthorectified so they represent true map distances. The DOQQs have a 1 m^2 resolution and their analysis provides a high level of accuracy in the determination of impervious cover at a subwatershed scale. A point sampling method with a 200 m regular grid was used to evaluate the impervious area and a detailed description of the methodology and quality assurance assessment is provided in Bird et al. (2001). The DOQQ sampling yielded an average of approximately 800 sample points per 14-digit HUC–with a total of 43,816 points in the study area.

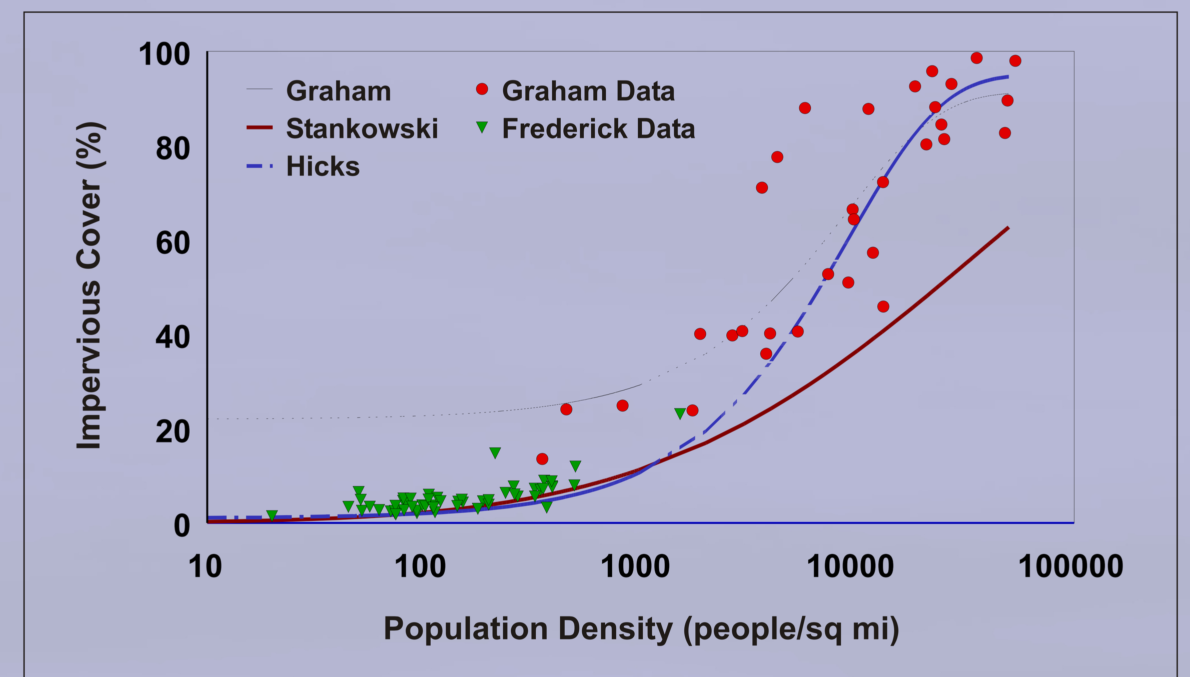
Frederick County is a suburban community northwest of Baltimore, MD and Washington, DC and is experiencing rapid growth. The decade between 1980 and 1990 showed a 31% increase in population and the decade between 1990 and 2000 showed a 33% increase. Urban sprawl in this area is causing the decline of prime agricultural land primarily in the central portion of the county.



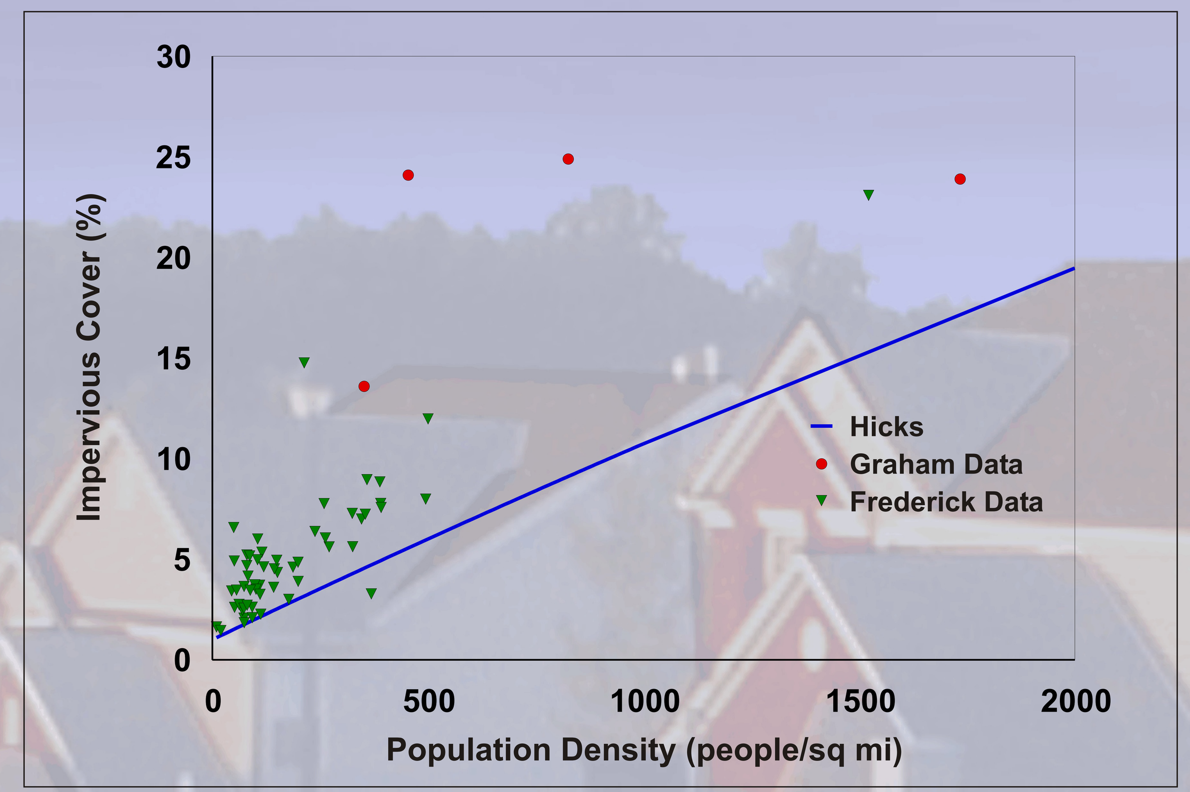
Using Population Density

Impervious cover is a result of human settlement and population density should be a good predictor of impervious cover. The use of population density to estimate impervious cover is attractive since it provides a rapid technique for generating a quantitative estimation of present and projected land surface cover. Stankowski (1972), Graham et al. (1974), and Hicks and Woods (2000) developed empirical relationships with different functional forms to relate population density to percentage impervious cover.

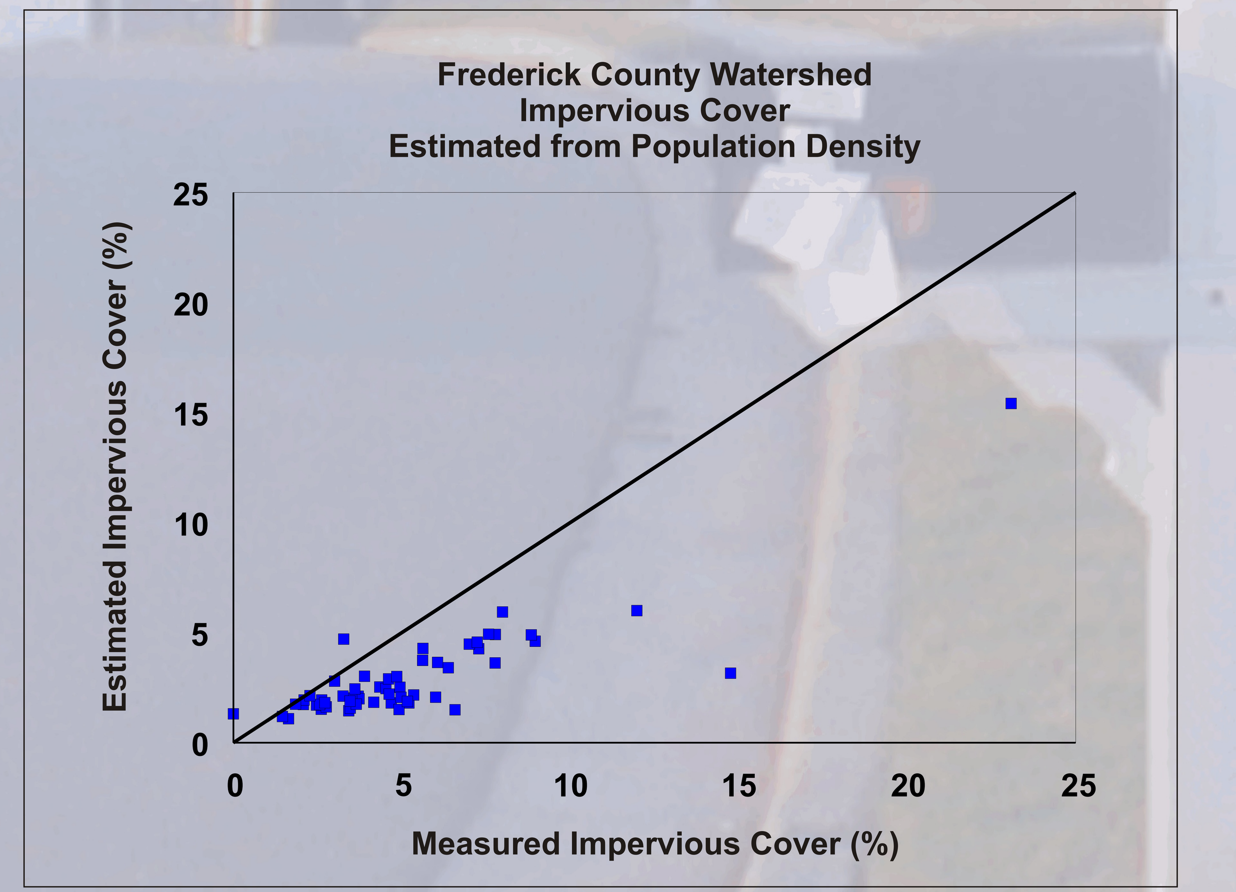
Stankowski's relationship seriously underpredicts impervious area at population densities greater than 1000 persons/mi^2, while Graham's clearly underpredicts % total impervious area (TIA) for population densities under 500 persons/mi^2.



The Hicks and Woods' (2000) relationship fits the overall response better than Graham or Stankowski. A closer examination of the Hicks and Woods' curve at population densities under 2000 person/mi^2 plotted using a linear x-axis indicates that this function consistently underestimates % TIA in this range.



For the Frederick County data, Hicks and Woods' (2000) relationship underpredicts impervious cover 2.2% on average. The Hicks and Woods' (2000) relationship was developed for a set of watersheds in the Greater Vancouver area where impervious cover was estimated based on land use.

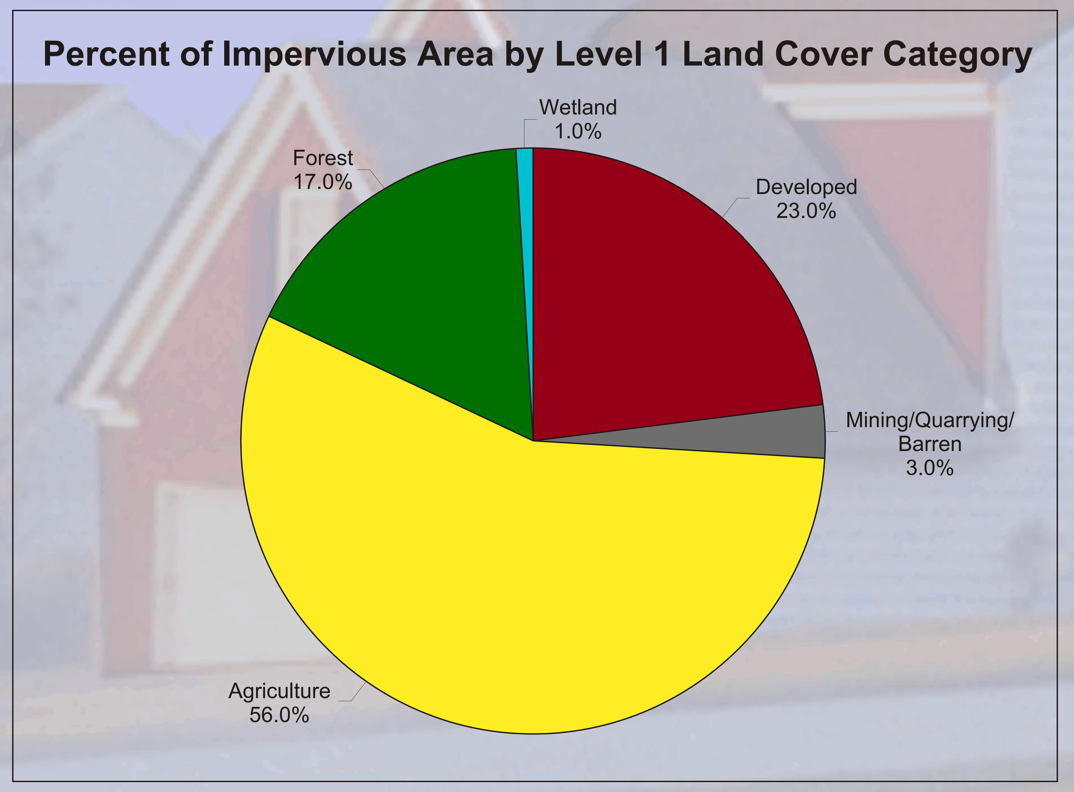


MRLC Projection

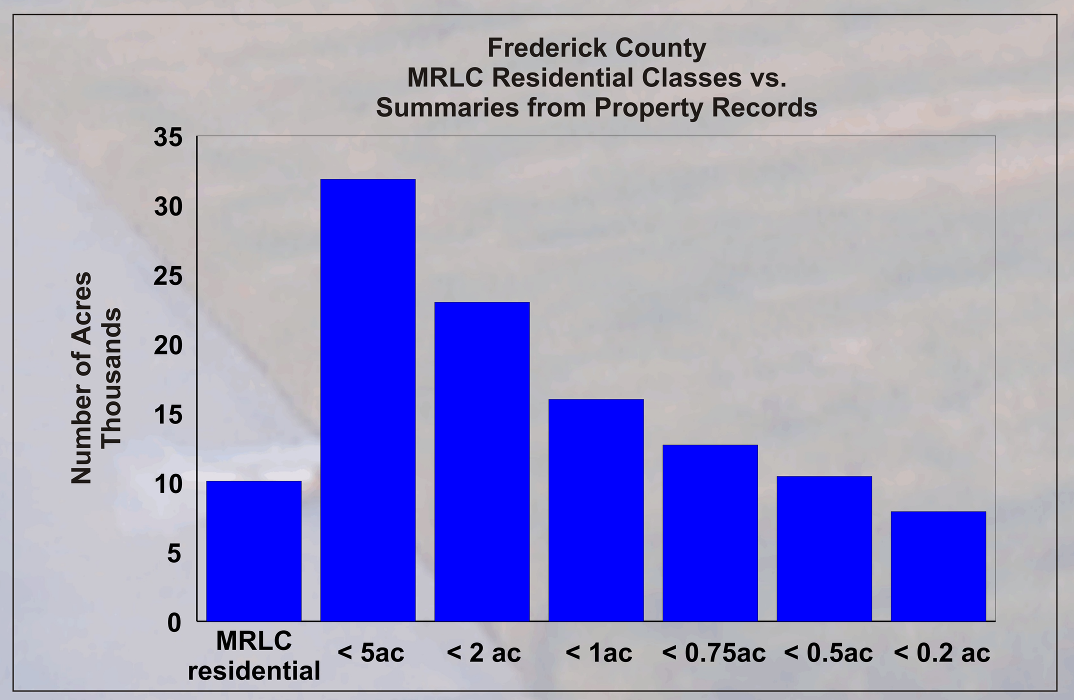
Land use and land cover data are frequently used as a basis for estimating impervious area. Categorized land use and land cover systems for use with remote sensing data define developed land cover classes based on the fraction of impervious cover in a specified area. Percent impervious coefficients for generalized land use and land cover data can be developed from satellite imagery such as the 30 m Landsat Thematic Mapper imagery. The Frederick County impervious surface data derived from the DOQQs was used to develop impervious surface coefficients for the MRLC categorized land cover data. These coefficients were calculated based on the percentage of sampling points classified as impervious that were located in the 30 m cells of the specific land cover category and are summarized in the following table.

Land Cover Category	Percentage of the Category Impervious	Sample Size	Percent of Impervious Area in Frederick County Accounted for by Category
low density residential	42	990	16.9
high density residential	77	76	2.4
commercial/ industrial	57	156	3.6
quarries/mines/ gravel pits	62	117	2.9
transitional barren	17	29	0.2
deciduous forest	2	11159	9.1
evergreen forest	4	697	1.1
mixed forest	5	3400	6.9
hay/pasture	5	23497	47.7
row crops	8	2663	8.6
other grasses	9	33	0.1
woody wetland	3	368	0.4
herbaceous wetland	1	138	0.1

The sample size column is the number of sampling points from the analysis of the DOQQs that were located in the specific land cover category. The final column in the table is the percentage of the impervious area in the county that is accounted for by the specified land cover class. Approximately 1/4 of the impervious area of Frederick County is accounted for within cells that are classified as developed. Nearly half of the impervious area was in the hay/pasture category. The relatively small fraction of the impervious area accounted for within a developed land class suggests that use of the categorized land cover will not be a reliable approach for evaluating impervious cover in suburban areas.

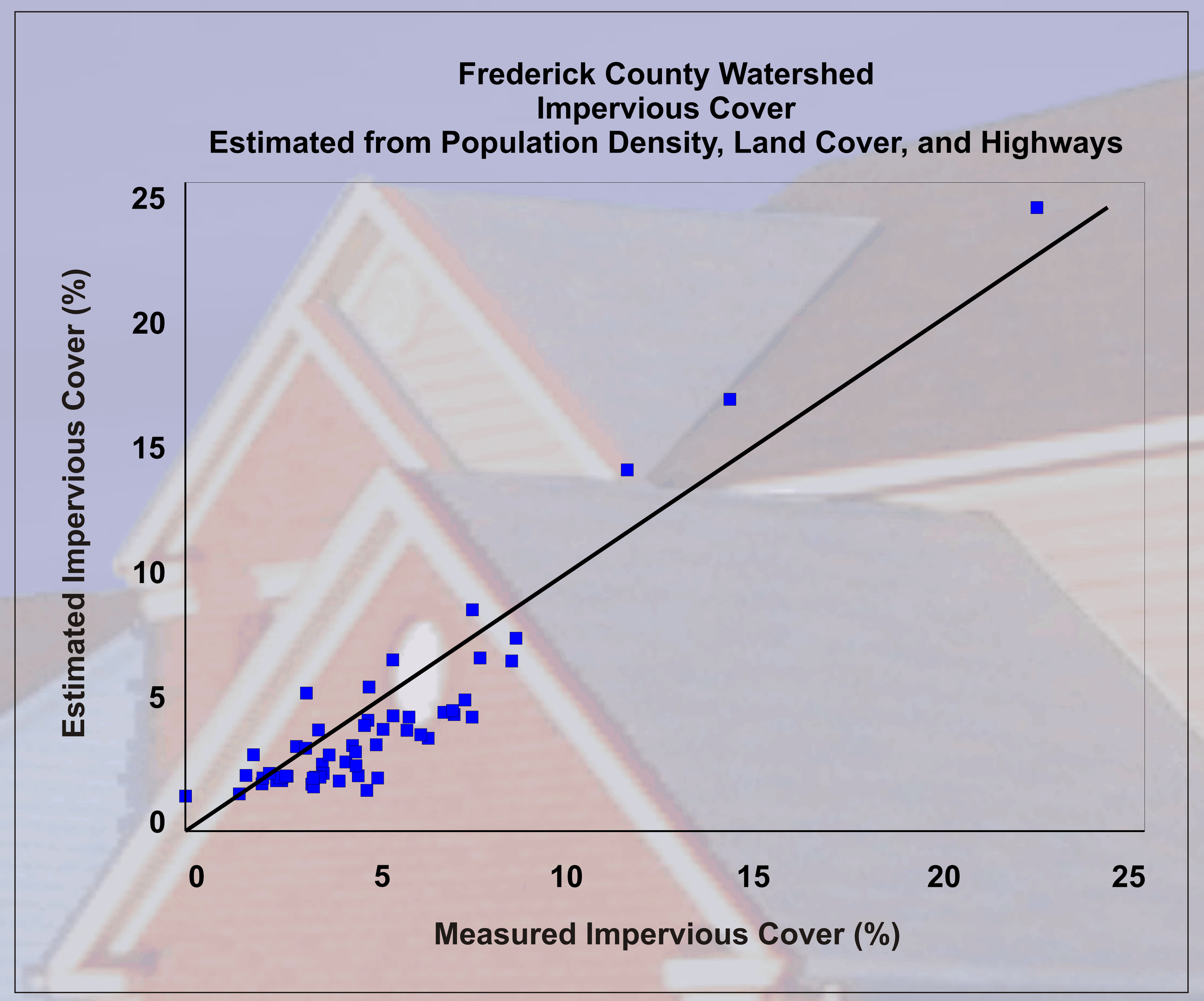


Residential area was compared to the area in buildings on residential properties from property tax records (MdProperty View) in the graph below. The acreage in the MRLC residential categories was less than the total acreage of residential properties on 0.5 acre or smaller lots. Larger lot development does not appear to be characterized as residential in the MRLC.



Combining Data Sources to Estimate Impervious Cover

Impervious cover arising from residential development will be a direct function of population density and should be captured by relationships such as those developed by Hicks and Woods (2000). Although commercial and industrial development has an indirect association with residential areas, the accounting of impervious cover with population density for this category is not direct. Satellite imagery more easily identifies high intensity commercial and industrial areas than dispersed suburban developments. Small streets and roads are generally associated with residential development but interstates and other major highways cut through sparsely settled areas as well. Combining multiple data sources should allow more accurate estimation of impervious cover. Impervious area in the Frederick County watersheds was estimated by adding estimates of impervious cover based on the Hicks and Woods' (2000) population density relationship, contribution from the industrial/commercial and quarries, mines and barren areas from the MRLC data, and a contribution from Class 1 and 2 roadways (Department of Transportation coverages) which include interstate and major US highways.



Overall, this method slightly underpredicted impervious cover with an average error of 0.8% and an absolute average error of 1.4%. The maximum error was 3.3%. This approach did not use any calibration or derivation of coefficients but rather relied on definitions of the land cover category and contribution of highways based on number of lanes and lane width in combination with a population density relationship developed from another region. Perfect agreement between estimated and measured impervious cover would fall along the solid line in the graph. The approximation method worked reasonably well for the range of the data in Frederick County. The number of comparison points over 10% was small and confidence in the method would be increased with additional measurements in this range. However, the approach of using multiple data sources as the basis appears to be a promising basis for estimating impervious cover.

Summary and Conclusions

Population density can be used to project impervious cover in watersheds. However, existing relationships tend to underpredict impervious cover in relatively low density (<2000 persons/sq mi) areas. Categorized satellite imagery does not adequately capture impervious cover in suburbanized areas at levels where initial degradation of water quality may be occurring. Use of block level census data to account for residential sources of impervious cover coupled with satellite imagery identifying commercial, manufacturing, mining, and quarrying along with road network information appears to be a promising approach for developing a usefully accurate impervious cover indicator.

Additional impervious cover data sets are being developed from aerial photographs for approximately 20 watersheds in the Atlanta area for two time periods. These data sets will be used as additional tests for methods presented here.

REFERENCES

Bird, S.L, Stephen W. Alberty and Linda R. Exum. 2001. Generating High Quality Impervious Cover Data. Journal of Quality Assurance, In Review.

Graham, P.H., Lawrence S. Costello and Harry J. Mallon. 1974. Estimation of Imperviousness and Specific Curb Length for Forecasting Stormwater Quality and Quantity, Journal Water Pollution Control Federation, 46(4):717-725.

Hicks, R.W.B. and Stan D. Woods. 2000. “Pollutant Load, Population Growth and Land Use.” *Progress:* Water Environment Research Foundation. 11:Page 10.

Loveland, T.R. and D.M. Shaw. 1996. Multiresolution Land Characterization: Building Collaborative Partnerships, *Gap Analysis: A Landscape Approach to Biodiversity Planning*. Proceedings of the ASPRS/GAP Symposium, Charlotte, North Carolina, National Biological Service, Moscow, Idaho, pp 83-89.

Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1 (3):100-111.

Stankowski, S.J. 1972. “Population Density as an Indirect Indicator of Urban and Suburban Land-Surface Modifications, U.S. Geological Survey, Professional Paper: Report 800B, B219-B224.

U.S. Environmental Protection Agency. 1994. The Quality of Our Nation's Water: 1992. Washington, DC.

Vogelmann. J.E., T. Sohl and S.M. Howard (1998). "Regional Characterization of Land Cover Using Multiple Sources of Data." Photogrammetric Engineering & Remote Sensing 64(1): 45-57.

Zandbergen, Paul, Jayna Houston, and Hans Schreier. 2000. Comparative Analysis of Methodologies for Measuring Watershed Imperviousness. Paper read at Watershed Management 2000 Conference, 2000.